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DRAFT REGULATORY GUIDE

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DRAFT REGULATORY GUIDE DG-1029

GUIDELINES FOR EVALUATING ELECTROMAGNETIC AND RADIO-FREQUENCY INTERFERENCE IN SAFETY-RELATED INSTRUMENTATION AND CONTROL SYSTEMS

A. INTRODUCTION

Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," contains General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," which requires that structures, systems, and components important to safety be designed to accommodate the effects of environmental conditions associated with nuclear power plant service conditions (including postulated accident conditions). Furthermore, 10 CFR 50.49 and 50.55a address verification measures such as testing that can be used to check the adequacy of design. Related requirements are contained in General Design Criteria 1, 2, 13, 21, 22, and 23 of Appendix A to 10 CFR Part 50, as well as in Criterion III, "Design Control," Criterion XI, "Test Control," and Criterion XVII, "Quality Assurance Records," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50. Additionally, Subpart B, "Standard Design Certifications," of 10 CFR Part 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants," addresses verification requirements for advanced reactor designs. Specifically, 10 CFR 52.47(a)(vi) requires that an application for design certification must state the tests, inspections,

This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received complete staff review and does not represent an official NRC staff position.

Public comments are being solicited on the draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Rules and Directives Branch, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Copies of comments received may be examined at the NRC Public Document Room, 2120 L Street NW., Washington, DC. Comments will be most helpful if received by **April 10, 1998.**

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analyses, and acceptance criteria that are necessary and sufficient to provide reasonable assurance that a plant will operate within the design certification.

Electromagnetic interference (EMI), radio-frequency interference (RFI), and power surges have been identified as environmental stressors that can affect the performance of electrical equipment that is important to safety. Therefore, controlling electrical noise and the susceptibility of instrumentation and control (I&C) systems to EMI/RFI and power surges is a necessary step in meeting the aforementioned requirements. The need to develop specific practices to address EMI/RFI and power surge issues in safety-related I&C systems is stated in NRC Policy Issue SECY-91-273, "Review of Vendors' Test Programs To Support the Design Certification of Passive Light Water Reactors."[1]

This regulatory guide describes design, installation, and testing practices acceptable to the NRC staff for addressing the effects of EMI/RFI and power surges on safety-related I&C systems in a nuclear power plant environment. Adherence to these practices applies to both safety-related I&C systems and non-safety-related I&C systems whose failures can affect safety functions. Rationale for the selection of the practices depicted in this guide is that they provide a well established, systematic approach for ensuring electromagnetic compatibility (EMC) and the capability to withstand power surges in I&C equipment within the environment in which it operates. The technical basis behind selecting these particular practices is given in NUREG/CR-5941, "Technical Basis for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related I&C Systems"[2] (April 1994), and a draft of NUREG/CR-6431, "Recommended Electromagnetic Operating Envelopes for Safety-Related I&C Systems in Nuclear Power Plants"[3] (December 1997).

Regulatory guides are issued to describe to the public methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to explain techniques used by the staff in evaluating specific problems or postulated accidents, and to provide guidance to

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[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

[2]Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

[3]Single copies of draft NUREG-series reports may be obtained free of charge by writing the Office of Administration, Attn: Printing, Graphics and Distribution Branch, USNRC, Washington, DC 20555-0001, or by fax at (301)415-5272. Copies of draft NUREGs are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; telephone (202)634-3273; fax (202)634-3343.

applicants. Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required. Regulatory guides are issued in draft form for public comment to involve the public in developing the regulatory positions. Draft regulatory guides have not received complete staff review; they therefore do not represent official NRC staff positions.

The information collections contained in this draft regulatory guide are covered by the requirements of 10 CFR Part 50, which were approved by the Office of Management and Budget, approval number 3150-0011. The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number.

B. DISCUSSION

The typical environment in a nuclear power plant includes many sources of electrical noise, for example, hand-held two-way radios, arc welders, switching of large inductive loads, high fault currents, and high-energy fast transients associated with switching at the generator or transmission voltage levels. The increasing use of advanced analog- and microprocessor-based I&C systems in reactor protection and other safety-related plant systems has introduced concerns with respect to the creation of additional noise sources and the susceptibility of this equipment to the electrical noise already present in the nuclear power plant environment.

Digital technology is constantly evolving, and manufacturers of digital systems are incorporating increasingly higher clock frequencies, faster operating speeds, and lower logic level voltages into their designs. Unfortunately, these performance advancements may have an adverse impact on the operation of digital systems with respect to EMI/RFI and power surges because of the increased likelihood of extraneous noise being misinterpreted as legitimate logic signals. With recent advances in analog electronics, many of the functions presently being performed by several analog circuits could be combined into a single miniaturized analog circuit operating at reduced voltage levels, thereby making analog circuitry more susceptible to EMI/RFI and power surges as well. Hence, operational and functional issues related to safety in the nuclear power plant environment must address the possibility of upsets and malfunctions in I&C systems caused by EMI/RFI and power surges.

This guide endorses Institute of Electrical and Electronics Engineers (IEEE) Std 1050-1996, "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating

Stations,"[4] with one exception as stated in Regulatory Position 2. IEEE Std 1050-1996 is a revision of IEEE Std 1050-1989 and addresses three of the four exceptions taken to the technical content of that standard. The four exceptions were cited in NUREG/CR-5941. IEEE Std 1050-1996 provides guidance on the engineering practices needed to control upsets and malfunctions in safety-related I&C systems when exposed to EMI/RFI and power surges. The Energy Development and Power Generation Committee of the IEEE Power Engineering Society sponsored the development of IEEE Std 1050-1996 and the IEEE Standards Board approved the standard. IEEE Std 1050-1996 was developed to provide guidance on the design and installation of grounding systems for I&C equipment specific to power generating stations. Further purposes of the standard are to achieve both a suitable level of protection for personnel and equipment and suitable electrical noise immunity for signal ground references in power generating stations.

IEEE Std 1050-1996 addresses grounding and noise-minimization techniques for I&C systems in a generating station environment. Recommended practices for the treatment of both analog and digital systems are included that address the grounding and shielding of electronic circuits on the basis of minimizing emissions and their susceptibility to EMI/RFI and power surges. The standard is comprehensive in that it covers both the theoretical and practical aspects of grounding and electromagnetic compatibility.

Design verification measures for EMI/RFI testing (emissions and susceptibility) are beyond the scope of IEEE Std 1050-1996. To determine the adequacy of safety-related I&C system designs, the NRC staff has endorsed the applicable EMI/RFI test criteria in Military Standard (MIL-STD) 461, "Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference,"[5] and the associated test methods in MIL-STD 462, "Measurement of Electromagnetic Interference Characteristics."[5] These are cited in Regulatory Positions 3, 4, and 5 and include both the MIL-STD 461C and 461D EMI/RFI test criteria, as well as the associated MIL-STD 462 and 462D test methods. MIL-STD 461 and 462 were developed as measures to ensure the electromagnetic compatibility of equipment. The application of the MIL-STD test criteria and test methods is tailored for the intended function of the equipment and the characteristic environment (i.e., which tests are applied and what levels are used depend on the function to be performed and the location of operation). These

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[4]IEEE publications may be purchased from the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08855-1331.

[5]Military Standards are available from the Department of Defense, Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

standards have been used successfully by the U.S. Department of Defense for many years and are commonly referenced in commercial applications.

Design verification measures for power surge withstand testing are also beyond the scope of IEEE Std 1050-1996. Accordingly, the NRC has endorsed the test criteria recommended in IEEE Std C62.41-1991 (Reaffirmed in 1995), "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits,"[4] and the associated test methods recommended in IEEE Std C62.45-1992, "IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits,"[4] in Regulatory Position 6. The Surge Protective Devices Committee of the IEEE Power Engineering Society sponsored the development of IEEE Std C62.41-1991 and IEEE Std C62.45-1992 and the IEEE Standards Board approved the standards. IEEE Std C62.41-1991 provides guidance for the selection of voltage and current surge test criteria for evaluating the surge withstand capability (SWC) of equipment connected to low-voltage ac power circuits. Selection of the SWC test criteria is based on location within the facility, power line impedance to the surge, and available energy content. The standard also defines a set of surge test waveforms that has manageable dimensions and represents a baseline surge environment. IEEE Std C62.45-1992 provides guidance on the test methods and equipment to be employed when performing the surge tests.

General operating envelopes that form the basis for establishing EMI/RFI and power surge testing levels are cited in this guide. The technical basis for the electromagnetic operating envelopes is presented in NUREG/CR-6431. The operating envelopes are applicable for locations within a nuclear power plant where safety-related I&C systems either are or are likely to be installed. These locations include control rooms, cable spreading rooms, equipment rooms, relay rooms, auxiliary instrument rooms, and other areas (e.g., the turbine deck) where safety-related I&C system installations are planned. The operating envelopes are also applicable for both analog and digital system installations.

It is suggested that any modifications to the electromagnetic operating envelopes (e.g., lower site-specific envelopes) be based on technical evidence comparable to that presented in NUREG/CR-6431. In effect, any relaxation in the operating envelopes should be based on actual measurement data collected in accordance with IEEE Std 473-1985 (Reaffirmed in 1991), "IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)."[4]

The NRC staff accepted the Electric Power Research Institute (EPRI) topical report TR-102323, "Guidelines for Electromagnetic Interference Testing in Power Plants," in a Safety Evaluation Report (SER) attached to a letter dated April 17, 1996, from Bruce Boger, NRC, to Carl Yoder, EPRI/Utility Working Group Chairman.[1] The regulatory guidance in this guide is intended to be consistent with the position set forth in the SER. Both this guide and the SER endorsing EPRI's guidance in TR-102323 adhere to the same overall approach and are generally in agreement. Both documents recommend EMI/RFI-limiting practices based on IEEE Std 1050, endorse emissions and susceptibility test criteria and test methods to evaluate safety-related I&C systems, and identify appropriate operating envelopes for equipment and systems intended for selected locations in nuclear power plants without requiring additional plant-specific electromagnetic measurements.

The 1996 SER accepted the EMI/RFI engineering practices in IEEE Std 1050-1989. The SER accepted selected test criteria and test methods in MIL-STD 461C, MIL-STD 461D, and International Electrotechnical Commission (IEC) 801, "Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment,"[6] as appropriate means for assessing the electromagnetic compatibility of safety-related I&C system designs. In this regulatory guide, only the military standards are endorsed because the IEC 801 standard has not been made final and was recently superseded by IEC 61000-4, "Electromagnetic Compatibility, Part 4: Testing and Measurement Techniques."[6] The test criteria and test methods addressed in IEC 801 are roughly equivalent to those covered by the MIL-STDs, IEEE Std C62.41, and IEEE Std C62.45. The most significant difference between the testing approaches is found in the applicability of transient test criteria. The MIL-STD and IEEE test methods are not generally used for assessing conducted susceptibility across interconnecting signal lines, whereas IEC 801 does contain such provisions. Therefore, because of the focus on the MIL-STD and IEEE test criteria, this guidance does not address signal line conducted susceptibility explicitly. Since it is conceivable that signal line transients could disrupt the performance of safety-related I&C systems, the SER position represents current guidance for addressing this issue.

Some areas of the Regulatory Position in this guide offer options to the guidance discussed in the SER. First, Regulatory Position 2 endorses the 1996 version (rather than the 1989 version) of IEEE Std 1050, which outlines the engineering practices needed to control EMI/RFI- and surge-related upsets and malfunctions in safety-related I&C systems. Second, Regulatory Position 3 specifies only complete suites of EMI/RFI emissions and susceptibility criteria from the two most prominent military standards (i.e., no mixing and matching of test criteria and methods are recommended). Third, the electromagnetic operating envelopes that form the basis for establishing EMI/RFI testing levels are framed in suitable measurement units and frequency ranges for each specific test method. Fourth, the Regulatory Position guidance

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[6]International Electrotechnical Commission documents are available from the IEC at 3 rue de Varembe, PO Box 131, 1211 Geneva 20, Switzerland.

applies to analog, digital, and hybrid safety-related I&C systems since the nuclear power plant of the future may utilize all of them.

The EMI/RFI practices, SWC practices, and operating envelopes endorsed in this guide are only elements of the total package that is needed to ensure EMC within nuclear power plants. In addition to assessing the electromagnetic environment, plants will still need to apply sound engineering practices for nonsafety-related upgrades and I&C maintenance as part of an overall EMC program. While nonsafety-related systems are not part of the regulatory guidance being developed, control of EMI/RFI from these systems is essential to ensure that safety-related I&C systems can continue to perform properly in the nuclear power plant environment. It is suggested that, when feasible, the emissions from nonsafety-related systems be held to the same levels as safety-related systems.

C. REGULATORY POSITION

1. GENERAL

Establishing and continuing an electromagnetic compatibility program for safety-related I&C systems in nuclear power plants contributes to the assurance that structures, systems, and components important to safety are designed to accommodate the effects and to be compatible with the environmental conditions associated with nuclear power plant service conditions. Application of consensus standard practices regarding the design, testing, and installation of safety-related I&C system upgrades or new installations constitutes an important element of such a program. This guidance recommends design and installation practices to limit the impact of electromagnetic effects, testing criteria to assess the emissions and susceptibility of equipment, and testing criteria to evaluate the power surge withstand capability of the equipment. In addition, operating envelopes characteristic of the electromagnetic environment in nuclear power plants are cited as the basis for establishing acceptable testing levels.

The electromagnetic conditions at the point of installation for safety-related I&C systems should be assessed to identify any unique EMI/RFI sources that may generate local interference. The EMI/RFI sources could include both portable and fixed equipment (e.g., portable transceivers, arc welders, power supplies, and generators). Steps should be taken during installation to ensure that the systems are not exposed to EMI/RFI levels from the identified sources that are greater than 8 dB below the specified operating envelopes.

To ensure that the operating envelopes are being used properly, equipment should be tested in the same physical configuration as that specified for its actual installation in the plant. In addition, the physical configuration of the safety-related I&C system should be maintained and all changes in the configuration controlled. The design specifications that should be maintained and controlled include wire and cable separations, shielding techniques, shielded enclosure integrity, apertures, gasketing, grounding techniques, EMI/RFI filters, and circuit board layouts.

Exclusion zones should be established through administrative controls to prohibit the activation of portable transceivers in areas where safety-related I&C systems have been installed. An exclusion zone is defined as the minimum distance permitted between the point of installation and where portable transceivers are allowed to be activated. The size of the exclusion zones should be site-specific and depend on the effective radiated power and antenna gain of the portable transceivers used within a particular nuclear power plant. The size of exclusion zones should also depend on the allowable electric field emission levels designated for the area in the vicinity of the installed safety-related I&C system. To establish the size of an exclusion zone, an 8 dB difference between the susceptibility operating envelope and the allowed emissions level should be maintained. For the radiated electric field operating envelope of 10 V/m (140 dBμV/m), the size of the exclusion zones should be set such that the radiated electric fields emanating from the portable transceivers are limited to 4 V/m (132 dBμV/m) in the vicinity of safety-related I&C systems. The minimum distance of an exclusion zone (d) in meters should be calculated by:

$$d = (30PG)^{0.5}/E$$

where

P = the effective radiated power of the transceiver (in watts);

G = the gain of the transceiver antenna (assume G = 1 is worst case); and,

E = the allowable radiated electric field strength of the transceiver (in V/m) at the point of installation.

2. IEEE Std 1050-1996

IEEE Std 1050-1996, "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations," describes design and installation practices that are acceptable to the NRC staff regarding EMI/RFI- and power surge-related effects on safety-related I&C systems employed in nuclear power plants with the following exception.

Section 4.3.7.4, "Radiative Coupling," of the standard maintains that the "field strength" of propagating electromagnetic waves is inversely proportional to the square of the distance from the source of radiation. This statement needs to be reevaluated because radiative coupling is a far-field effect. A distance, r, greater than the wavelength divided by 2π ($r > \lambda/2\pi$) from the source of radiation is considered to be far field, which is the region where the wave impedance is equal to the characteristic impedance of the medium. Both the electric and magnetic "field strengths" fall off as $1/r$ in the far field, i.e., in inverse proportion to distance (not as its square). This concept is not to be confused with the propagation of electromagnetic waves in the near field ($r < \lambda/2\pi$) where the wave impedance is determined by the characteristics of the source and the distance from the source. In the near field, if the source impedance is high ($>377\Omega$), the electric and magnetic "field strengths" attenuate at rates of $1/r^3$ and $1/r^2$, respectively. If the source impedance is low ($<377\Omega$), the rates of attenuation are reversed: the electric "field strength" will fall off at a rate of l/r^2 and the magnetic "field strength" at a rate of $1/r^3$. The user should understand that radiative coupling is a far-field effect and the "field strength" falls off as $1/r$, not as $1/r^2$.

IEEE Std 1050-1996 references other standards that contain complementary and supplementary information. In particular, IEEE Std 518-1982 (Reaffirmed in 1990), "IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources,"[4] and IEEE Std 665-1995, "IEEE Guide for Generating Station Grounding,"[4] are referenced frequently. The portions of IEEE Std 518-1982 and IEEE Std 665-1995 referenced in IEEE Std 1050-1996 are endorsed by this guide and are to be used in a manner consistent with the practices in IEEE Std 1050-1996.

3. MIL-STD 461, "ELECTROMAGNETIC EMISSION AND SUSCEPTIBILITY REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE"

The EMI/RFI test criteria in MIL-STD 461D listed in Table 1, along with their corresponding MIL-STD 461C counterparts listed in Table 2, are acceptable to the NRC staff in regard to EMI/RFI effects on safety-related I&C systems in nuclear power plants. It is intended that either set be applied in its entirety, without selective application of individual criteria (i.e., no mixing and matching of test criteria). These criteria cover conducted and radiated interference (emissions and susceptibility), exposure to electric and magnetic fields, transients, and noise coupling through power and control leads. The criteria do not cover conducted interference on interconnecting signal lines.

General operating envelopes that are acceptable to the NRC staff are given with the listed EMI/RFI test criteria. These operating envelopes are acceptable for locations where safety-related I&C systems either are or are likely to be installed and include control rooms, cable spreading rooms, equipment rooms, auxiliary instrument rooms, relay rooms, and other areas (e.g., the turbine deck) where safety-related I&C system installations are planned. The operating envelopes are acceptable for both analog and digital system installations.

Table 1 Recommended MIL-STD 461D Test Criteria

Criterion	Description
CE101	Conducted emissions, power leads, 30 Hz to 10 kHz
CE102	Conducted emissions, power leads, 10 kHz to 10 MHz
CS101	Conducted susceptibility, power leads, 30 Hz to 50 kHz
CS114	Conducted susceptibility, bulk cable injection, 10 kHz to 400 MHz
RE101	Radiated emissions, magnetic field, 30 Hz to 100 kHz
RE102	Radiated emissions, electric field, 10 kHz to 1 GHz
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 10 kHz to 1 GHz

C = conducted, E = emissions, R = radiated, and S = susceptibility.

Table 2 MIL-STD 461C Counterparts to Applicable MIL-STD 461D Test Criteria

Criterion	Description
CE01	Conducted emissions, power leads, 30 Hz to 15 kHz
CE03	Conducted emissions, power leads, 15 kHz to 50 MHz
CS01	Conducted susceptibility, power leads, 30 Hz to 50 kHz
CS02	Conducted susceptibility, power and interconnecting control leads, 50 kHz to 400 MHz
RE01	Radiated emissions, magnetic field, 30 Hz to 30 kHz
RE02	Radiated emissions, electric field, 14 kHz to 1 GHz
RS01	Radiated susceptibility, magnetic field, 30 Hz to 50 kHz
RS03	Radiated susceptibility, electric field, 14 kHz to 1 GHz

C = conducted, E = emissions, R = radiated, and S = susceptibility.

4. TEST METHODS, MIL-STD 462D

The test methods that demonstrate compliance with the MIL-STD 461D EMI/RFI test criteria are specified in MIL-STD 462D, "Measurement of Electromagnetic Interference Characteristics." These test methods and their associated operating envelopes are discussed below.

4.1 CE101—Conducted Emissions, Low Frequency

The CE101 test measures the low-frequency conducted emissions on power leads of equipment and subsystems in the frequency 30 Hz to 10 kHz. Equipment tested under comparable power quality guidance should be exempt from this test. When the test is desired, it is applicable to ac and dc power leads, including grounds and neutrals, that obtain power from other sources not part of the equipment under test. Conducted emissions on power leads should not exceed the applicable root mean square (rms) values shown in Figure 4.1. The values are specified according to the type of power source that feeds the equipment under test.

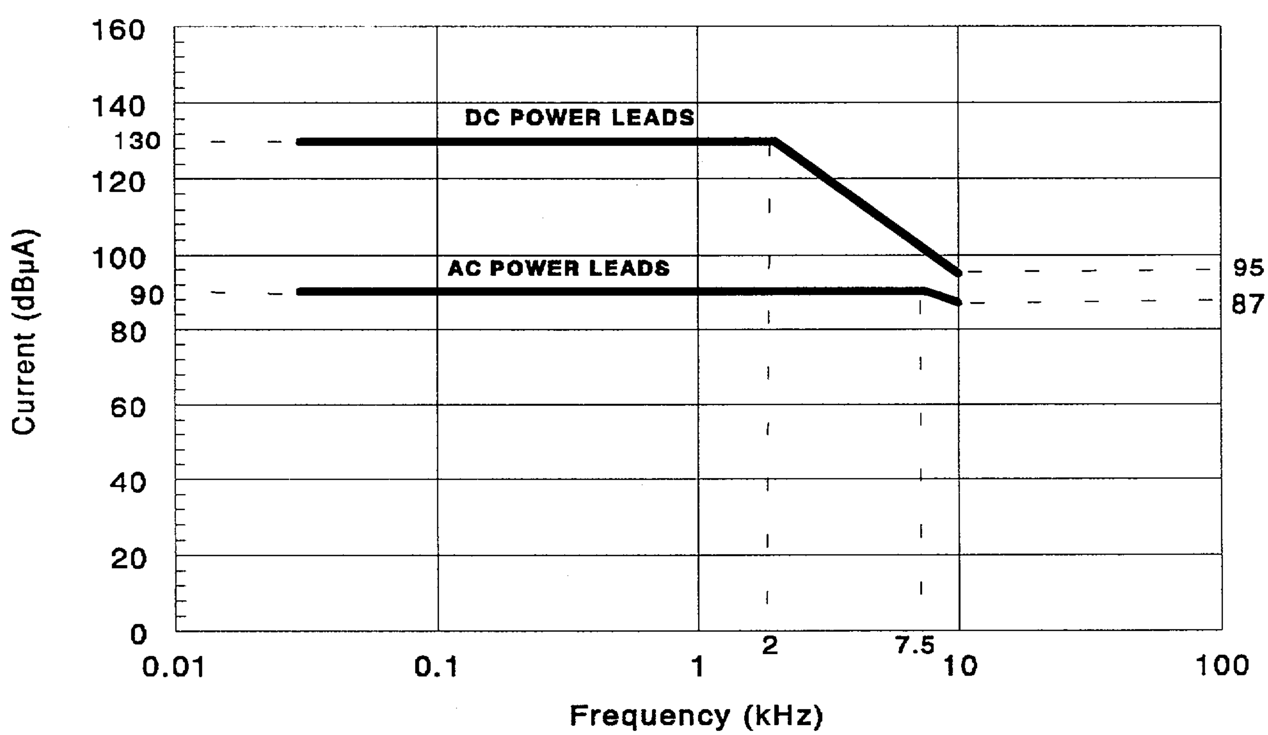

Figure 4.1 CE101 Emissions Envelopes

4.2 CE102—Conducted Emissions, High Frequency

The CE102 test measures the high-frequency conducted emissions on power leads of equipment and subsystems in the frequency range 10 kHz to 10 MHz. The test is applicable to ac and dc power leads, including grounds and neutrals, that obtain power from other sources that are not part of the equipment under test. Conducted emissions on power leads should not exceed the applicable rms values shown in Figure 4.2. The values are specified according to the voltage of the power source feeding the equipment under test.

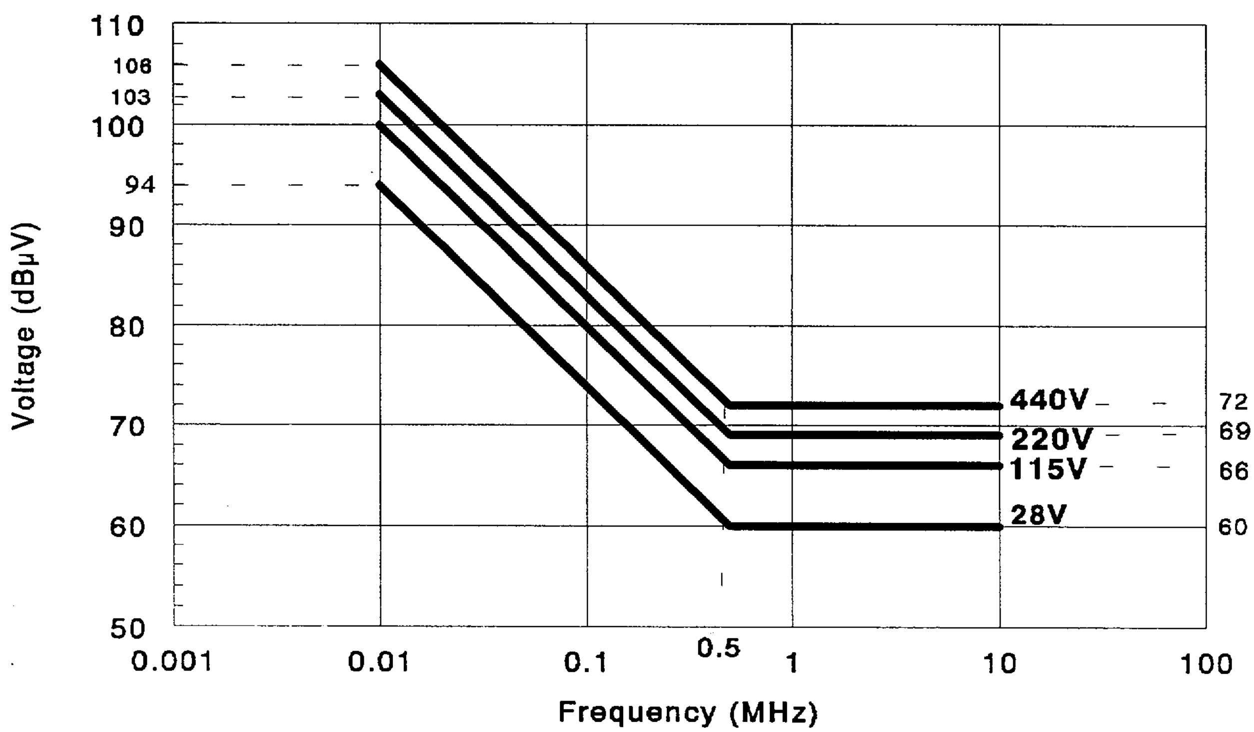

Figure 4.2 CE102 Emissions Envelopes

4.3 CS101—Conducted Susceptibility, Low Frequency

The CS101 test ensures that equipment and subsystems are not susceptible to EMI/RFI present on power leads in the frequency range 30 Hz to 50 kHz. The test is applicable to ac and dc input power leads, not including grounds and neutrals. If the equipment under test is dc operated, this test is applicable over the frequency range 30 Hz to 50 kHz. If the equipment under test is ac operated, this test is applicable starting from the second harmonic of the power frequency and extending to 50 kHz.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to a test signal with the rms voltage levels specified in Figure 4.3. The test criterion is also met when the power source specified in MIL-STD 462D, adjusted to dissipate 80 W in a 0.5-Ω load, cannot develop the required voltage (specified in Figure 4.3) at the power input terminals and the equipment under test is not adversely affected by the output of the signal. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

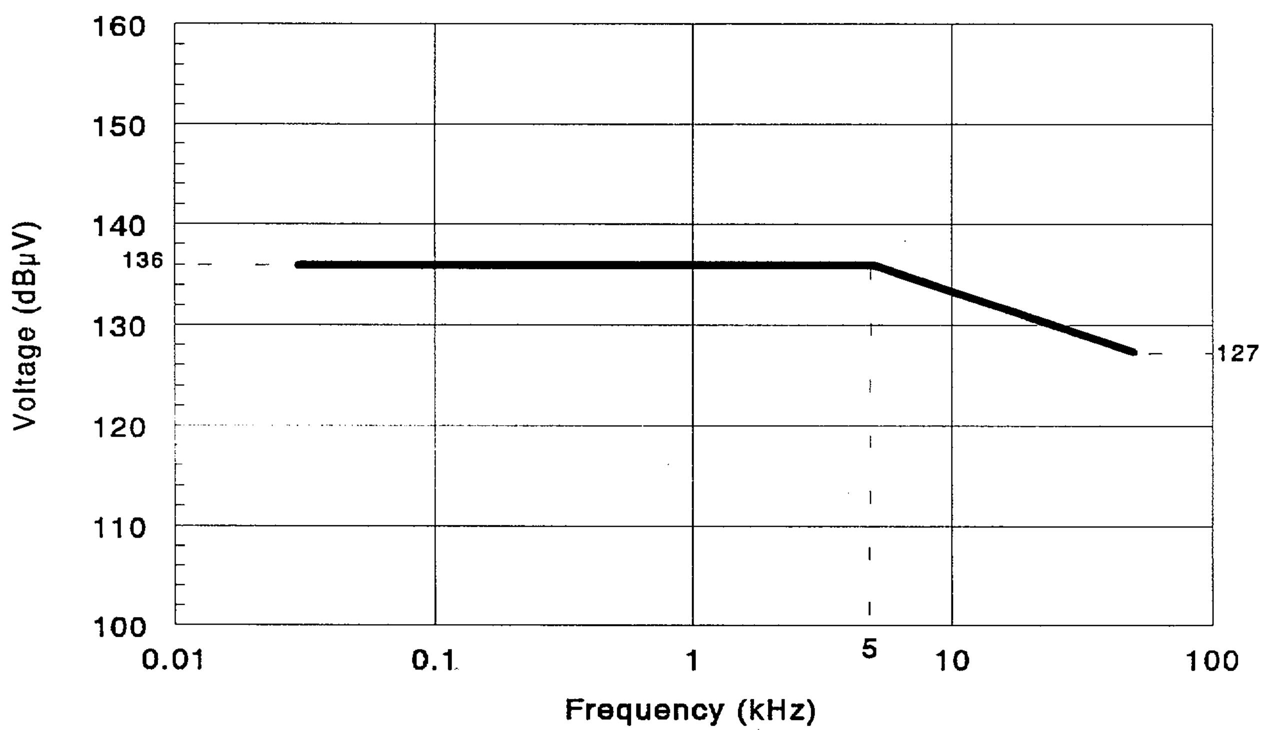

Figure 4.3 CS101 Operating Envelope

4.4 CS114—Conducted Susceptibility, High Frequency

The CS114 test simulates currents that will be developed on leads as a result of EMI/RFI generated by antenna transmissions. The test covers the frequency range 10 kHz to 400 MHz and is applicable to all interconnecting leads, including the power leads of the equipment under test. Although the CS114 test can be applied to assess signal line susceptibility, the test levels given apply only to power and control lines.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to a test signal with the rms levels shown in Figure 4.4. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

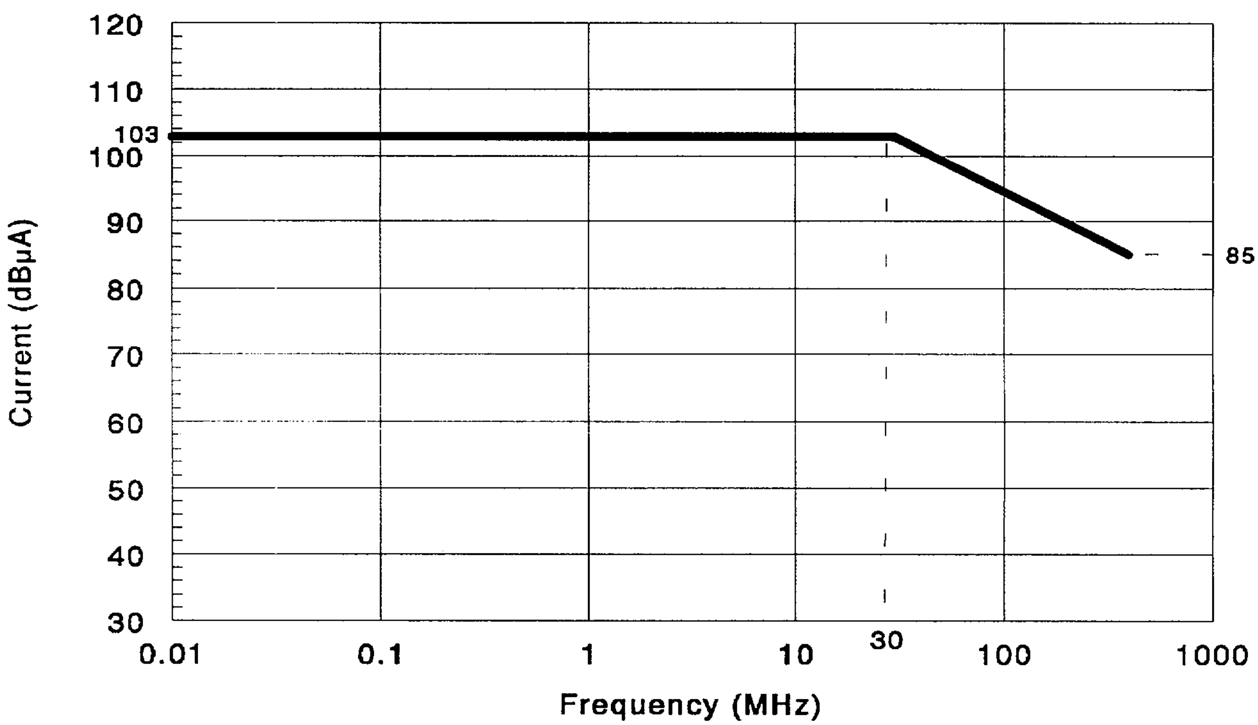

Figure 4.4 CS114 Operating Envelope

4.5 RE101—Radiated Emissions, Magnetic Field

The RE101 test measures radiated magnetic field emissions in the frequency range 30 Hz to 100 kHz. Equipment not intended to be installed in areas with other equipment sensitive to magnetic fields should be exempt from this test. The test is applicable for emissions from equipment and subsystem enclosures as well as all interconnecting leads. The test does not apply at transmitter fundamental frequencies or to radiation from antennas. Magnetic field emissions should not be radiated in excess of the levels shown in Figure 4.5 at the specified distances of 7 cm and 50 cm.

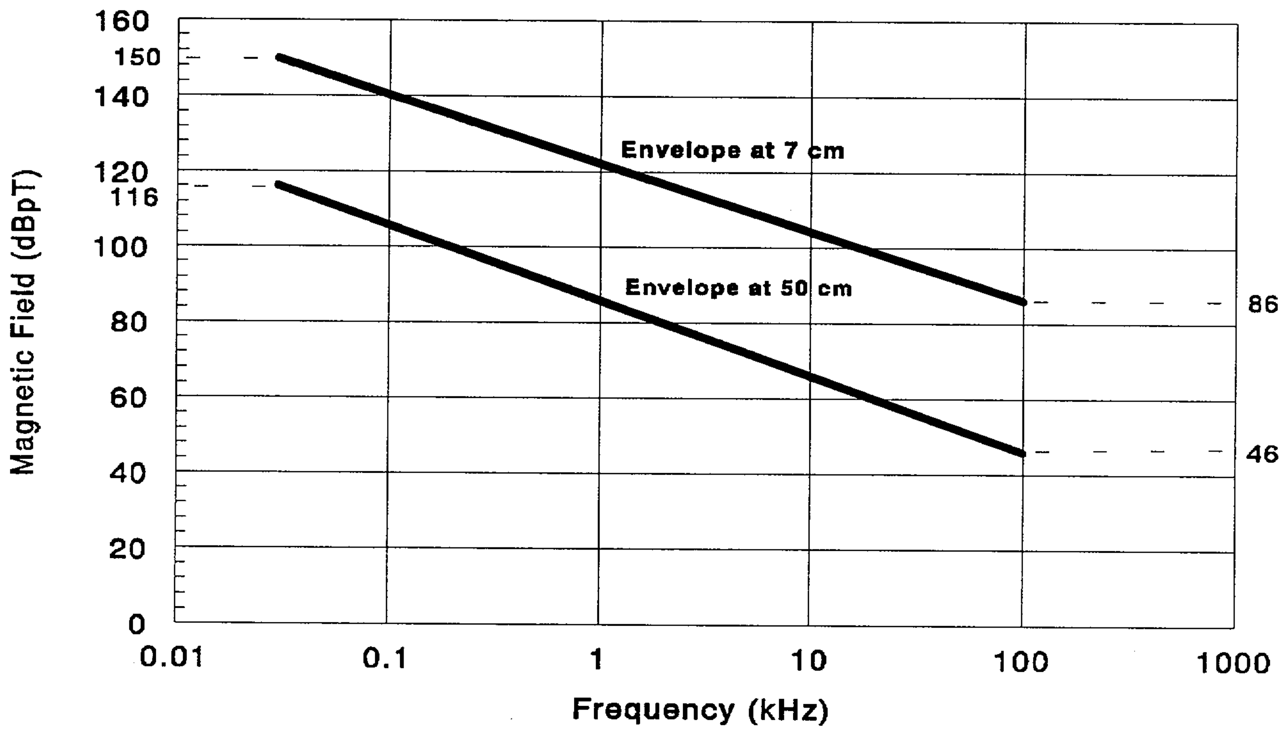

Figure 4.5 RE101 Magnetic Field Emissions Envelopes

4.6 RE102—Radiated Emissions, Electric Field

The RE102 test measures radiated electric field emissions in the frequency range 10 kHz to 1 GHz. It is applicable for emissions from equipment and subsystem enclosures, and all interconnecting leads. The test does not apply at transmitter fundamental frequencies or to radiation from antennas.

Electric field emissions should not be radiated in excess of the rms values shown in Figure 4.6. At frequencies above 30 MHz, the test criterion should be met for both horizontally and vertically polarized fields.

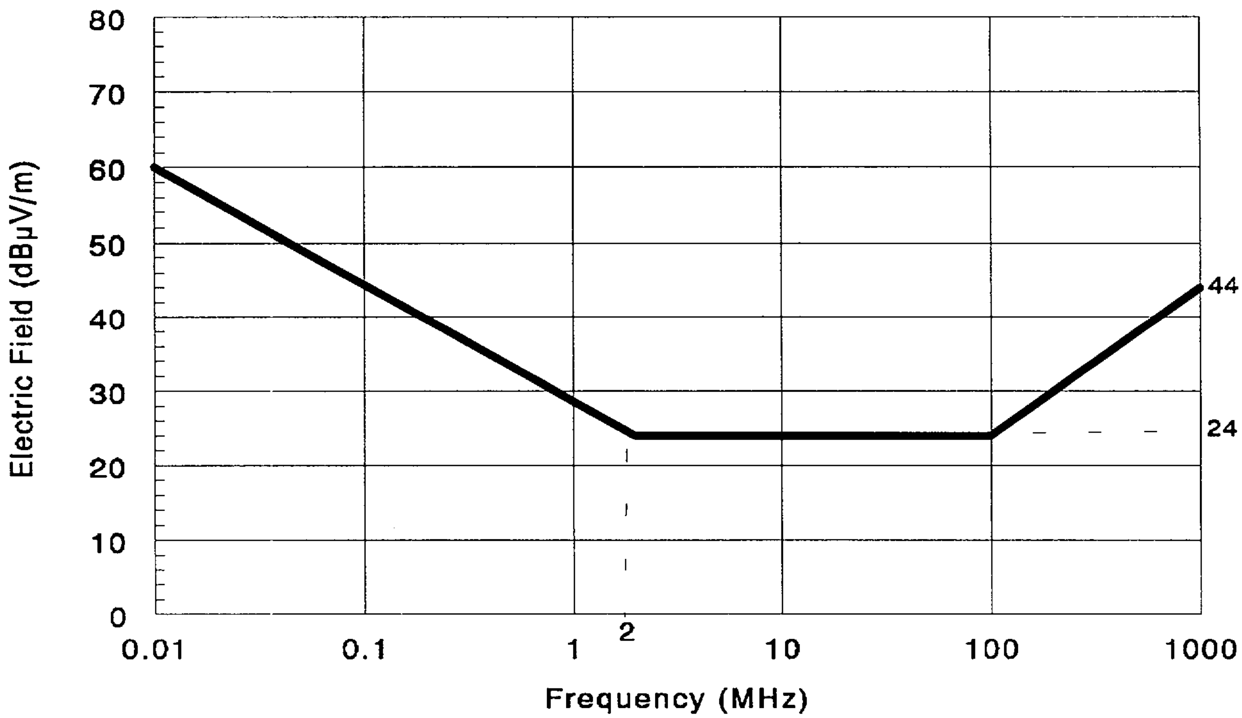

Figure 4.6 RE102 Emissions Envelope

4.7 RS101—Radiated Susceptibility, Magnetic Fields

The RS101 test ensures that equipment and subsystems are not susceptible to radiated magnetic fields in the frequency range 30 Hz to 100 kHz. The test is applicable to equipment and subsystem enclosures and all interconnecting leads. The test is not applicable for electromagnetic coupling via antennas.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the rms magnetic field levels shown in Figure 4.7. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

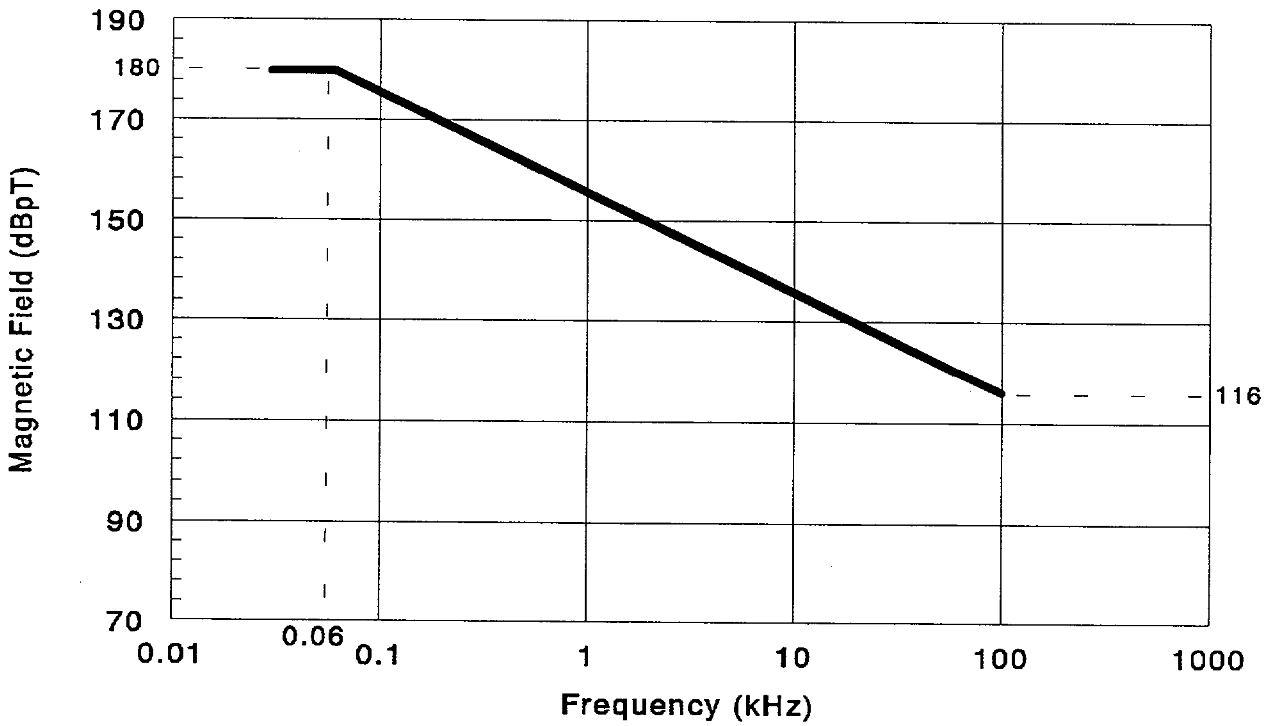

Figure 4.7 RS101 Operating Envelope

4.8 RS103—Radiated Susceptibility, Electric Fields

The RS103 test ensures that equipment and subsystems are not susceptible to radiated electric fields in the frequency range 10 kHz to 1 GHz. The test is applicable to equipment and subsystem enclosures and all interconnecting leads. The test is not applicable at the tuned frequency of antenna-connected receivers, unless otherwise specified.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the radiated electric fields. The impressed electric field level should be 10 V/m (rms), measured at the surface of the equipment under test with a field strength meter. The test criterion should be met for both horizontally and vertically polarized fields. According to MIL-STD 462D, circularly polarized fields are not acceptable because radiated electric fields are typically linearly polarized. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

5. TEST METHODS, MIL-STD 462

The test methods that demonstrate compliance with the MIL-STD 461C EMI/RFI test criteria are specified in MIL-STD 462, "Measurement of Electromagnetic Interference Characteristics." These test methods and their associated operating envelopes are discussed below.

5.1 CE01—Conducted Emissions, Low Frequency

The CE01 test measures the low-frequency conducted emissions on power leads of equipment and subsystems in the frequency range 30 Hz to 15 kHz. Equipment tested under comparable power quality guidance should be exempt from this test. When the test is desired, it is applicable to ac and dc power leads, including grounds and neutrals, that are not grounded internally to the equipment or subsystem. The test is not applicable to interconnecting signal leads.

The CE01 test is applicable for emissions on dc power leads from 30 Hz to 15 kHz. Conducted emissions on dc power leads in excess of the values shown in Figure 5.1 should not appear when measured with an effective bandwidth not exceeding 75 Hz. The CE01 test is applicable for emissions on ac power leads from the power line frequency to 15 kHz. Emissions on ac power leads in excess of the rms values shown in Figure 5.2 should not appear when measured with an effective bandwidth not exceeding the power line frequency plus 20% of the power line frequency (i.e., 72 Hz in the United States).

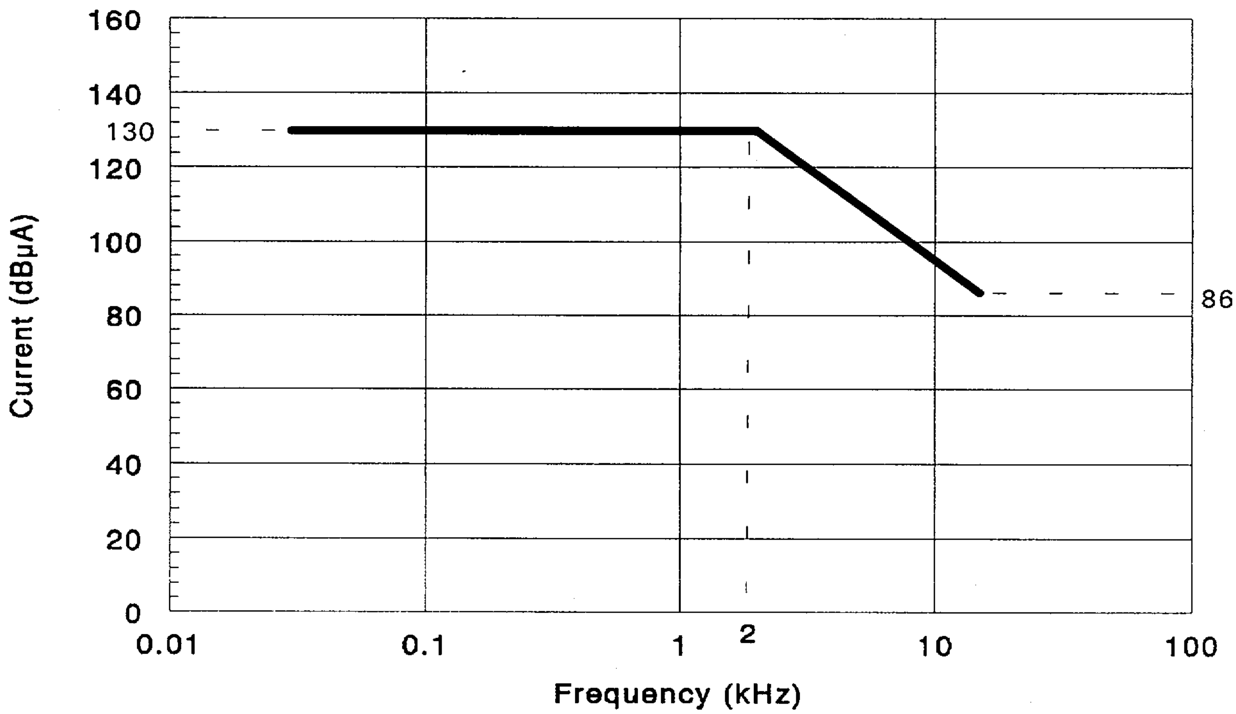

Figure 5.1 CE01 Emissions Envelope for dc Power Leads

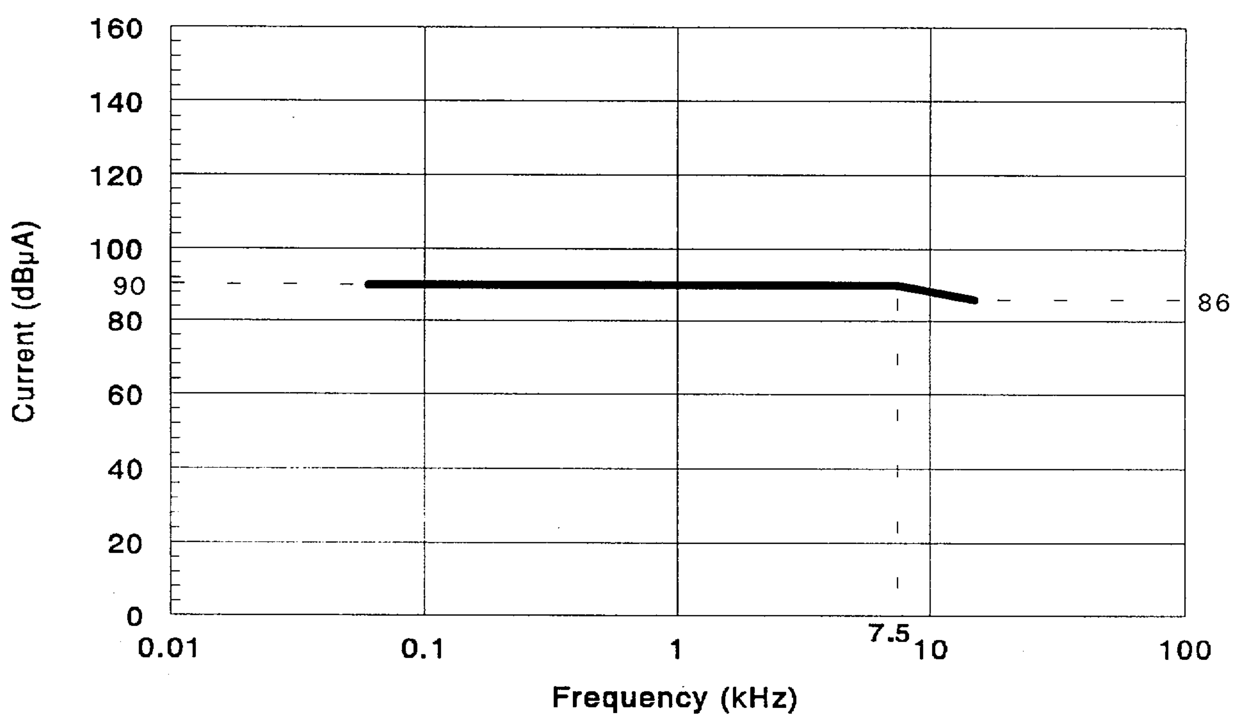

Figure 5.2 CE01 Emissions Envelope for ac Power Leads

5.2 CE03—Conducted Emissions, High Frequency

The CE03 test measures the high-frequency conducted emissions on power leads of equipment and subsystems in the frequency range 15 kHz to 50 MHz. The test is applicable to ac and dc power leads, including grounds and neutrals, that are not grounded internally to the equipment or subsystem. The test is not applicable to interconnecting signal leads. Conducted emissions should not appear on the power leads in excess of the rms values shown in Figures 5.3 and 5.4 for narrowband and broadband emissions, respectively.

The terms *narrowband* and *broadband* refer to the values for the measurement receiver bandwidths to be employed during the emissions testing. A factor of 10 is typically specified as the separation between the narrowband and broadband bandwidths, and it is used to differentiate between narrowband and broadband interference sources. If the interference is broadband (e.g., arc welders and motors), a reduction in the bandwidth by a factor of 10 on the measurement receiver should result in at least a 6 dB drop in the interference level. Otherwise, the interference is considered to be narrowband (e.g., two-way radios).

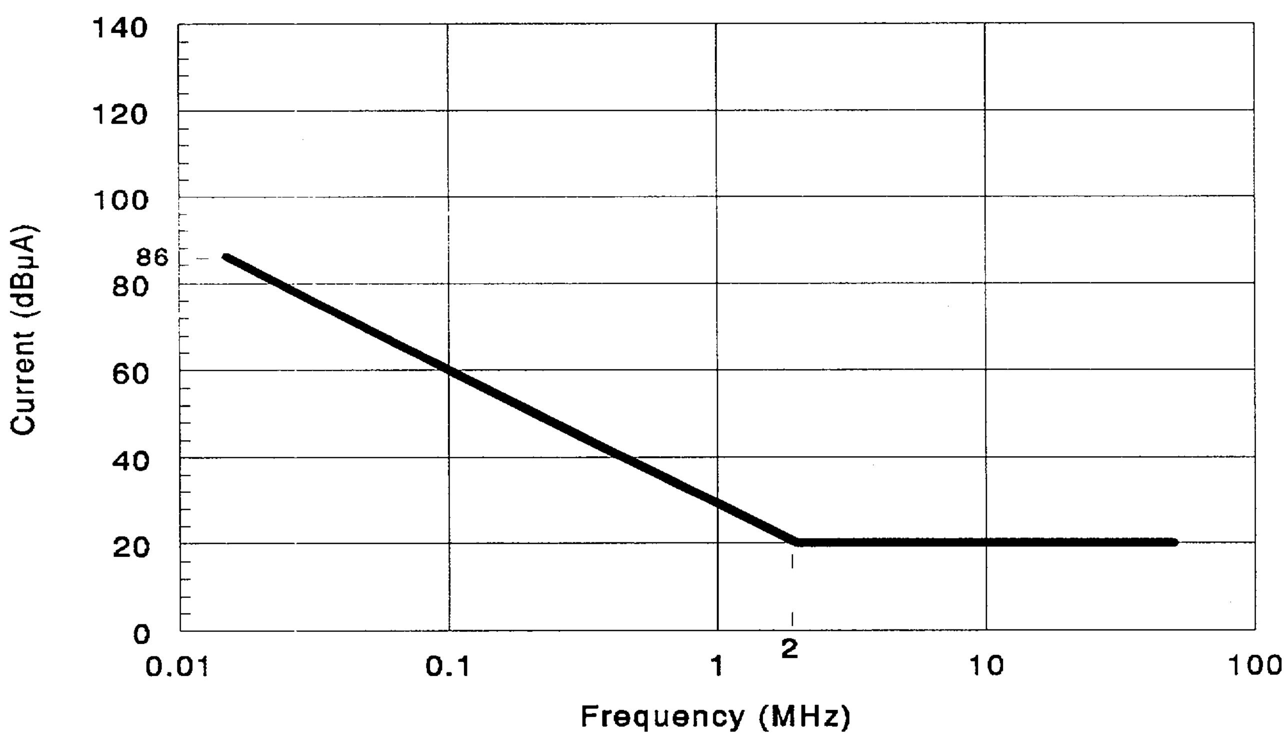

Figure 5.3 CE03 Narrowband Emissions Envelope

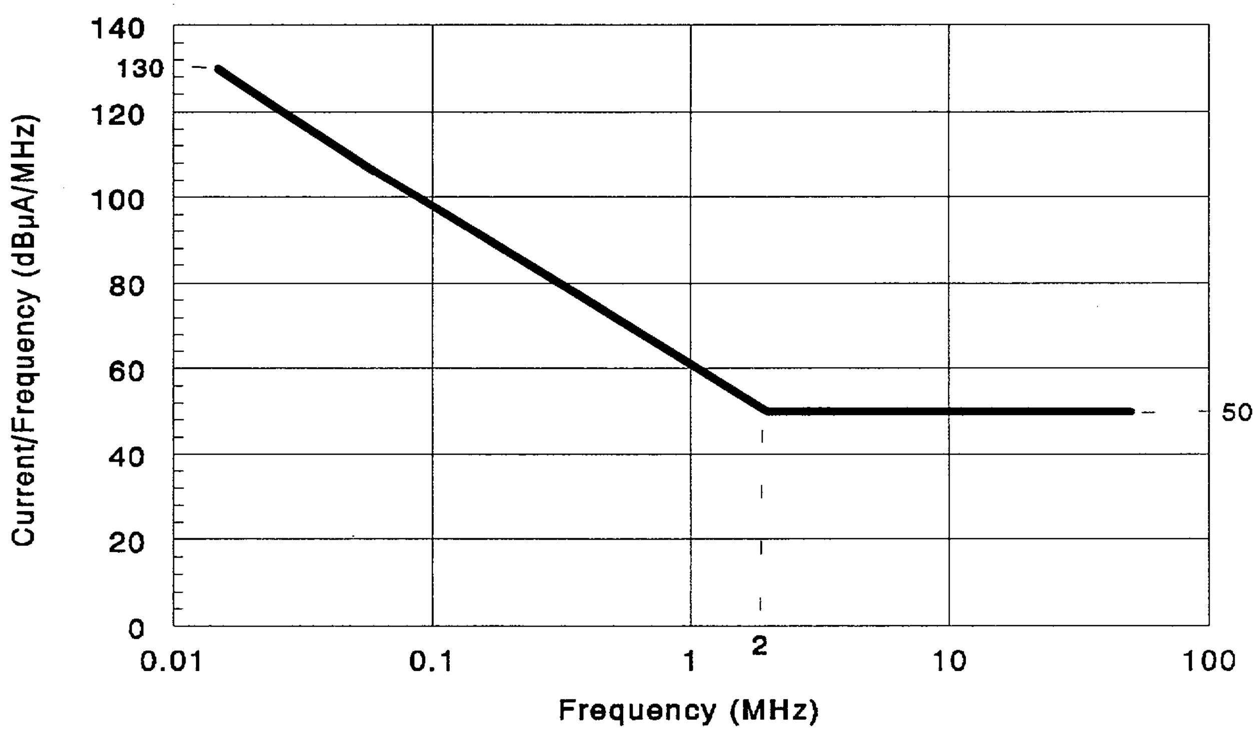

Figure 5.4 CE03 Broadband Emissions Envelope

5.3 CS01—Conducted Susceptibility, Low Frequency

The CS01 test ensures that equipment and subsystems are not susceptible to voltage distortions present on the power leads in the frequency range 30 Hz to 50 kHz. The test is applicable to ac and dc power leads, including grounds and neutrals, that are not grounded internally to the equipment or subsystem. The test is not applicable at frequencies within ±5% of the power line frequency (i.e., 57-63 Hz in the United States).

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to electromagnetic energy injected onto its power leads at the levels and frequencies given in Figure 5.5. The test criterion can also be met when the power source specified in MIL-STD 462, adjusted to dissipate 50 W into a 0.5-Ω load, cannot develop the required voltage (specified in Figure 5.5) at the power input terminals of the equipment under test and the equipment is not adversely affected by the output of the signal source. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

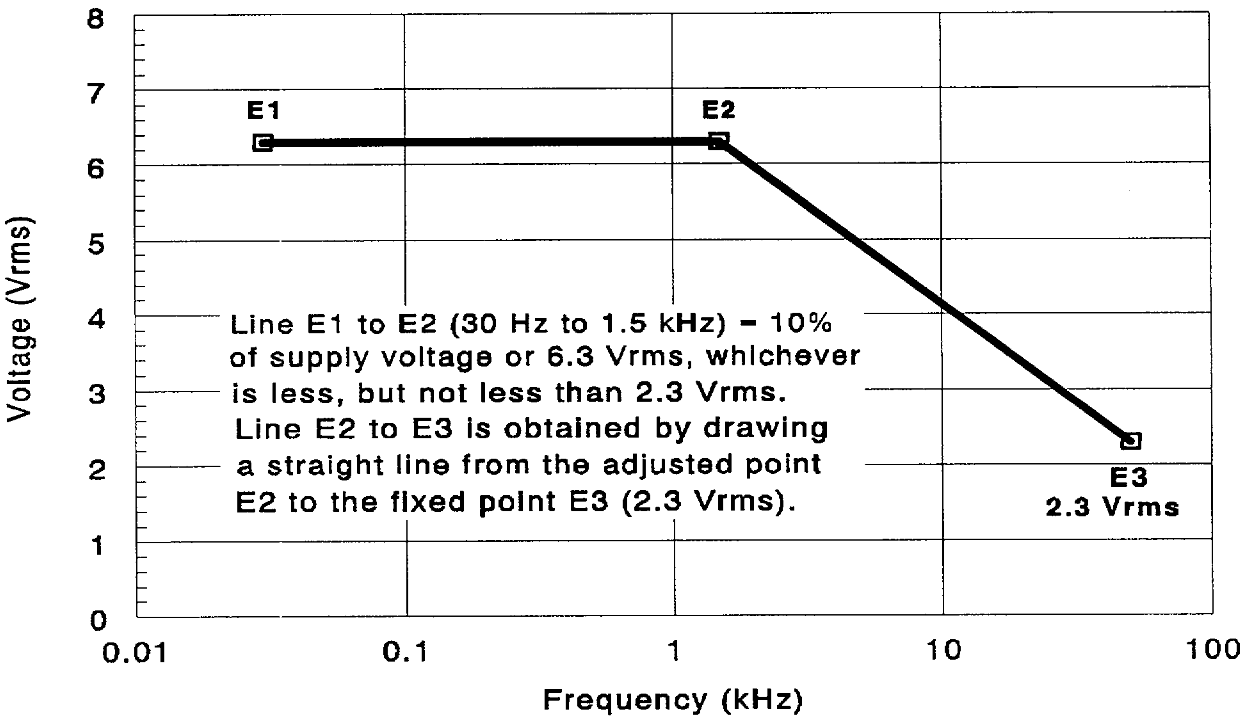

Figure 5.5 CS01 Operating Envelope

5.4 CS02—Conducted Susceptibility, High Frequency

The CS02 test is similar to the CS01 test except that it covers the higher frequency range 50 kHz to 400 MHz. The CS02 test is applicable to equipment and subsystem ac and dc power leads, including grounds and neutrals, that are not grounded internally to the equipment or subsystem.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to 7 Vrms from a 50-Ω source across the frequency range cited above. The test signal should be applied directly to the equipment input terminals, not through its power line cord. The criterion can also be met when a 1-W source of 50-Ω impedance cannot develop 7 Vrms at the input terminals of the equipment under test and the equipment is not adversely affected by the output of the signal source. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

5.5 RE01—Radiated Emissions, Magnetic Field

The RE01 test measures the radiated magnetic field emissions from equipment and subsystems in the frequency range 30 Hz to 30 kHz. Equipment not intended to be installed in areas with other equipment sensitive to magnetic fields should be exempt from this test. Also, the test does not apply to radiation from antennas. When the test is desired, levels should be measured with a receiving antenna positioned 7 cm from the surface of the equipment under test. Radiated magnetic field emissions should not appear at the receiving antenna in excess of the rms values shown in Figure 5.6.

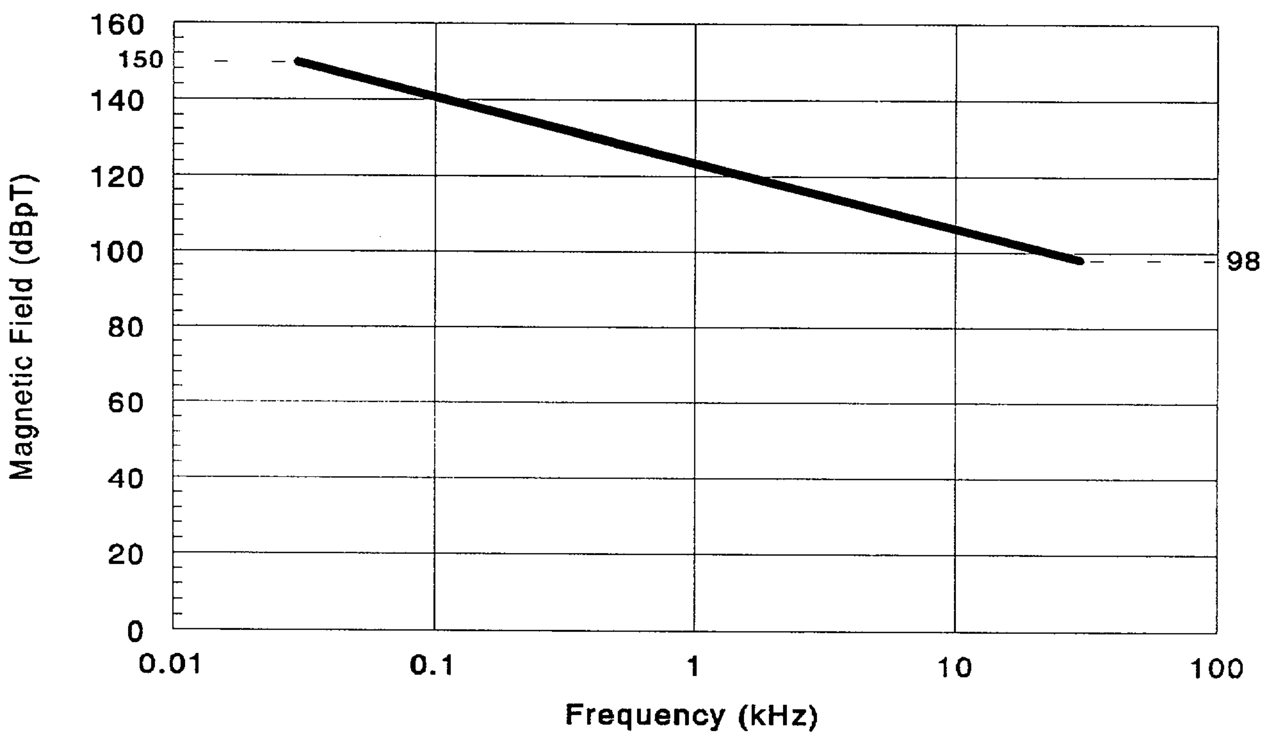

Figure 5.6 RE01 Magnetic Field Emissions Envelope

5.6 RE02—Radiated Emissions, Electric Field

The RE02 test measures the radiated electric field emissions from equipment and subsystems in the frequency range 14 kHz to 1 GHz. The test does not apply to radiation from antennas. Levels should be measured with receiving antennas positioned 1 m from the surface of the equipment under test. Radiated electric field emissions should not appear at the receiving antennas in excess of the rms values shown in Figures 5.7 and 5.8.

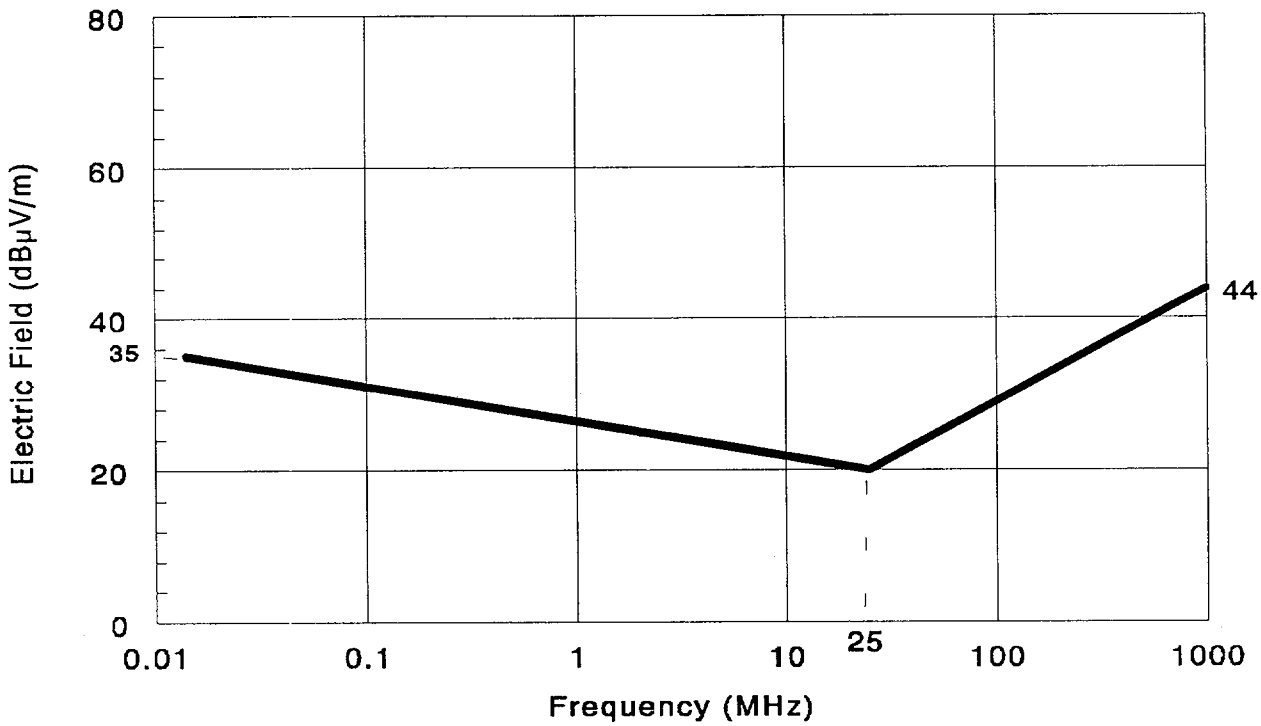

Figure 5.7 RE02 Narrowband Emissions Envelope

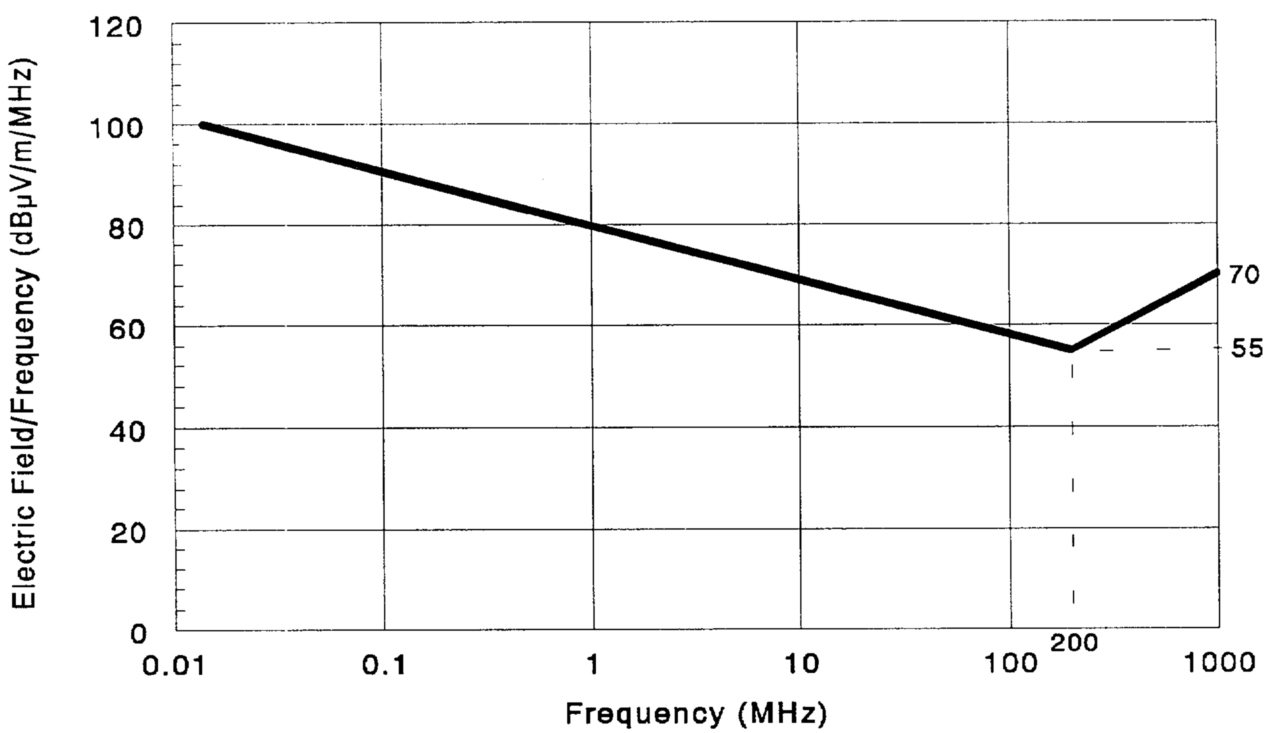

Figure 5.8 RE02 Broadband Emissions Envelope

5.7 RS01—Radiated Susceptibility, Magnetic Fields

The RS01 test ensures that equipment and subsystems are not susceptible to radiated magnetic fields in the frequency range 30 Hz to 50 kHz. A radiating loop antenna, positioned 5 cm from the equipment under test, is used to generate the magnetic fields.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the rms magnetic field levels and frequencies shown in Figure 5.9. The level of the imposed field is to be measured with a field strength meter positioned at the surface of the equipment under test. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

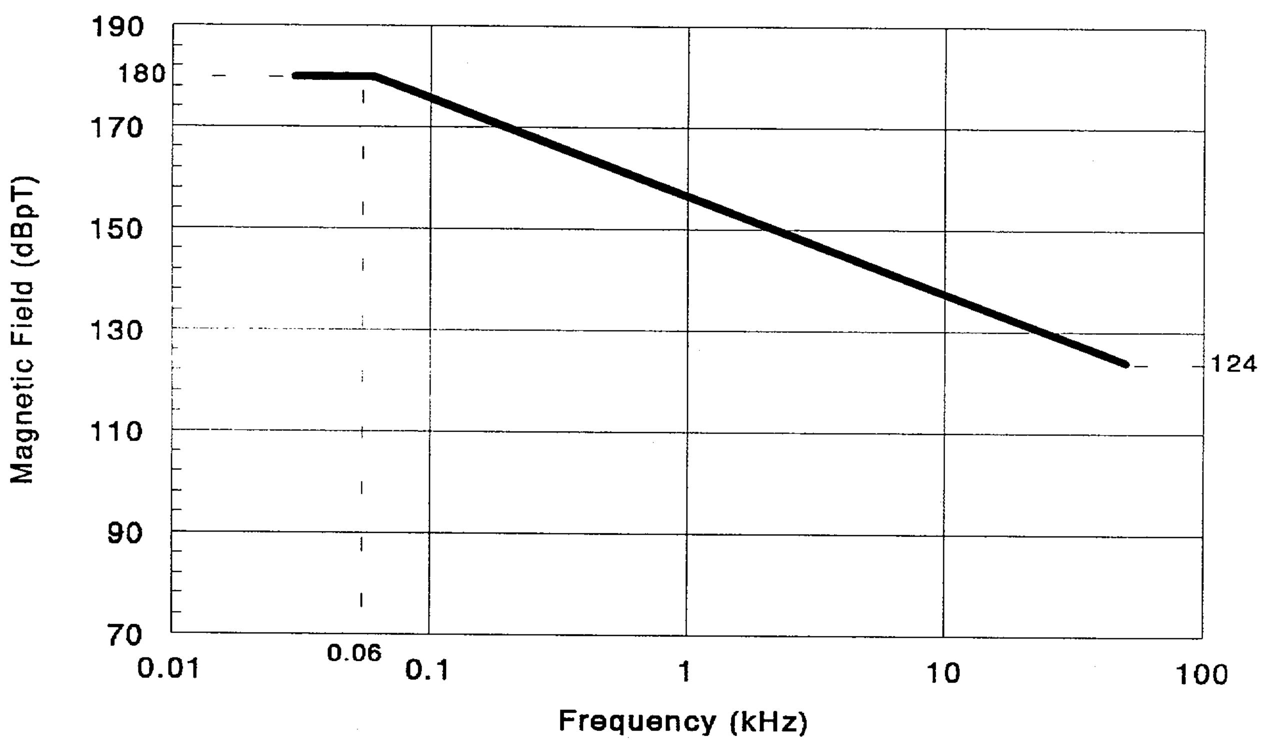

Figure 5.9 RS01 Operating Envelope

5.8 RS03—Radiated Susceptibility, Electric Fields

The RS03 test ensures that equipment and subsystems are not susceptible to radiated electric fields in the frequency range 14 kHz to 1 GHz. The fields are to be generated with high-impedance antennas selected to cover the specified frequency range.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to radiated electric fields. The electric field level impressed should be 10 V/m (rms), measured at the surface of the equipment under test with a field strength meter. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

6. PRACTICES IN IEEE STD C62.41-1991 AND IEEE STD C62.45-1992

The SWC practices described in IEEE Std C62.41-1991 (Reaffirmed in 1995), "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits," and IEEE Std C62.45-1992, "IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits," are acceptable to the NRC staff regarding the effect of power surges on safety-related I&C systems in nuclear power plants. IEEE Std C62.41-1991 defines a set of surge test waveforms that has manageable dimensions and represents a baseline surge environment. IEEE Std C62.45-1992 describes the associated test methods and equipment to be employed when performing the surge tests. Typical environmental conditions for power surges in a nuclear power plant can be represented by the waveforms given in Table 3.

Table 3 Representative Power Surge Waveforms

Parameter	Ring Wave	Combination Wave		EFT
Waveform	Open-circuit voltage	Open-circuit voltage	Short-circuit current	Pulses in 15-ms bursts
Rise time	0.5 μs	1.2 μs	8 μs	5 ns
Duration	100 kHz ringing	50 μs	20 μs	50 ns

Location categories and exposure levels are outlined in IEEE Std C62.41-1991 and define applicable amplitudes for the surge waveforms that should provide an appropriate degree of SWC. Location categories are defined as *Category A, B,* or *C,* depending on the proximity of equipment to the service entrance and the associated line impedance. *Category C* is exterior to an installation, *Category B* covers feeders and short branch circuits less than 10 m from the service entrance, and *Category A* covers long branch circuits greater than 10 m from the service entrance. Exposure levels are designated according to the rate of occurrence versus the voltage level (e.g., surge crest) to which equipment is exposed and range from *Low* to *High*. A *Low Exposure* level describes systems in areas known for little load or capacitor switching and low-power surge activity, while a *Medium Exposure* level describes systems in areas known for significant switching transients or medium- to high-power surge activity. A *High Exposure* level covers those rare installations that have greater surge exposures than those defined by *Low Exposure* and *Medium Exposure*. SWC exposure levels acceptable to the NRC staff are discussed below. These withstand levels are based on a *Category B* location and a *Low to Medium Exposure* level.

6.1 Ring Wave

The Ring Wave simulates oscillatory surges of relatively high frequency on the ac power leads of equipment and subsystems and is represented by an open-circuit voltage waveform. The waveform is an 100-kHz sinusoid having an initial rise time of 0.5 μs and continually decaying amplitude. A plot of the waveform is shown in Figure 6.1. The rise time is defined as the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The amplitude of the waveform decays with each peak being 60% of the amplitude of the preceding peak of the opposite polarity.

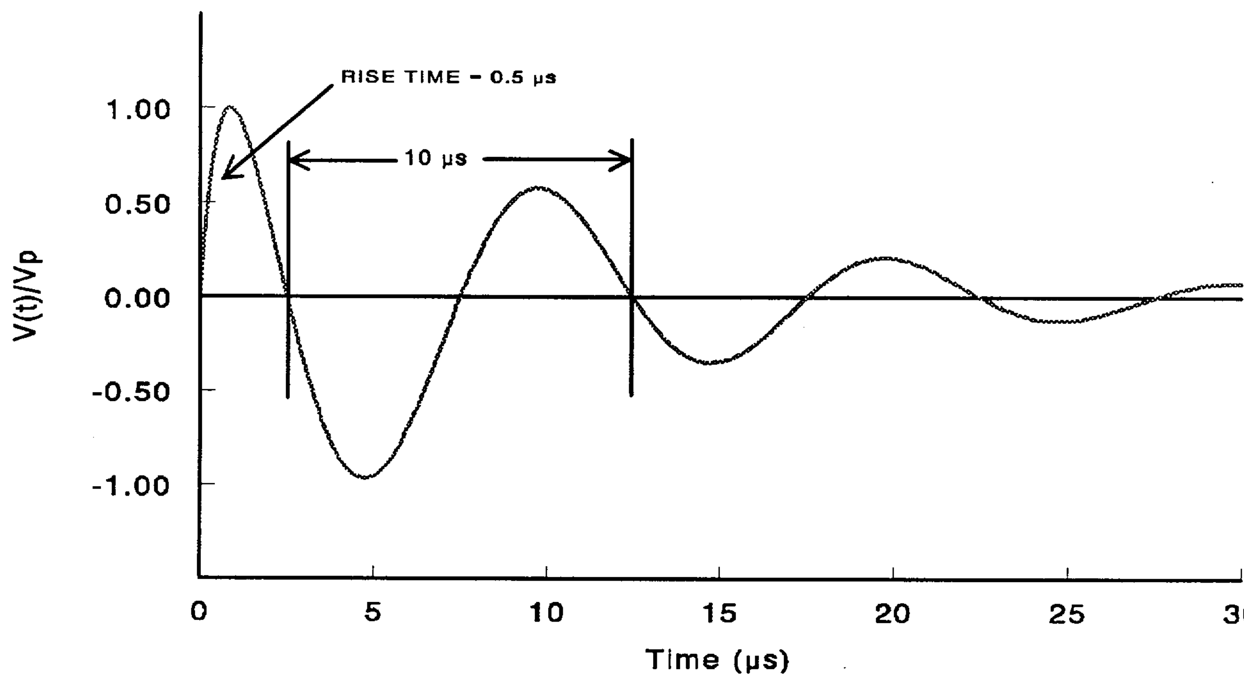

Figure 6.1 100-kHz Ring Wave

V_p, the peak voltage value of the Ring Wave, should be 3 kV. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the Ring Wave. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

6.2 Combination Wave

The Combination Wave involves two exponential waveforms, an open-circuit voltage and a short-circuit current. It is intended to represent direct lightning discharges, fuse operation, or capacitor switching on the ac power leads of equipment and subsystems. The open-circuit voltage waveform has a 1.2-μs rise time and an exponential decay with a duration (to 50% of initial peak level) of 50 μs. The short-circuit current waveform has an 8-μs rise time and a duration of 20 μs. Plots of the waveforms are shown in Figures 6.2 and 6.3.

The rise time is defined as the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time between virtual origin and the time at the 50% amplitude point on the tail of the waveform. Virtual origin is the point where a straight line between the 30% and 90% points on the leading edge intersects the 50% point on the tail of the waveform.

V_p, the peak value of the open-circuit voltage of the Combination Wave, should be 3 kV. I_p, the peak value of the short-circuit current, should be 1.5 kA. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the Combination Wave. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

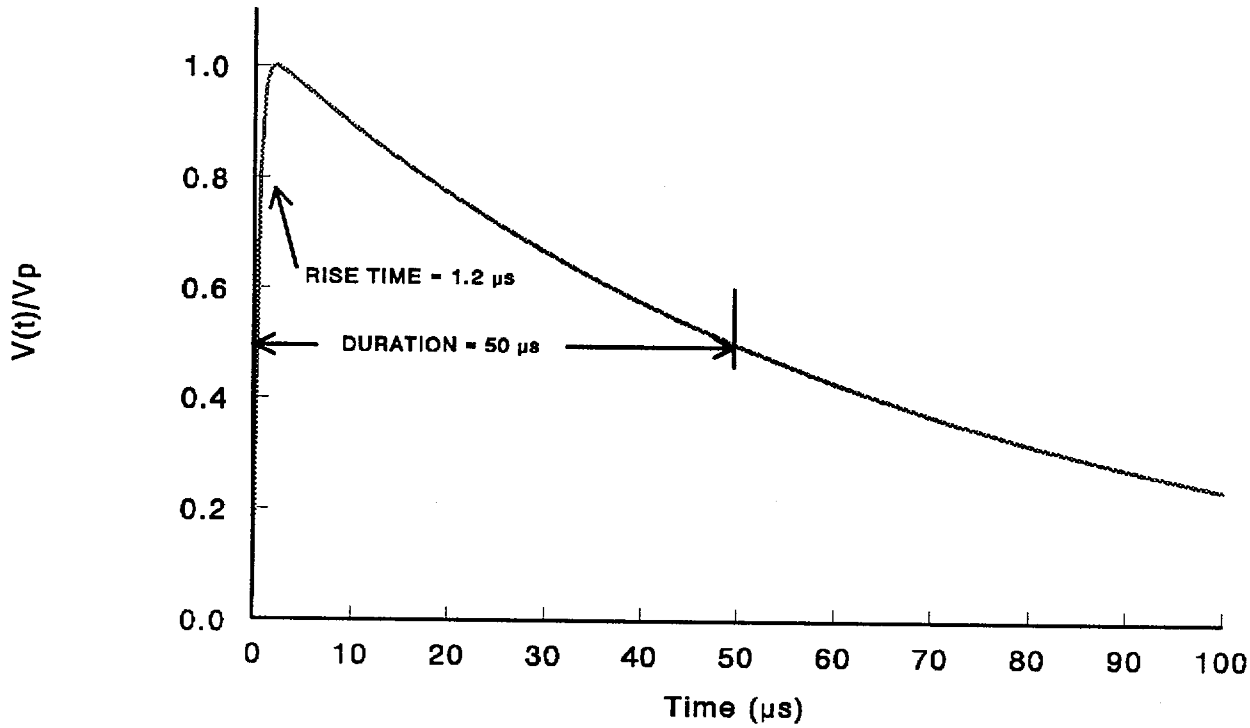

Figure 6.2 Combination Wave, Open-Circuit Voltage

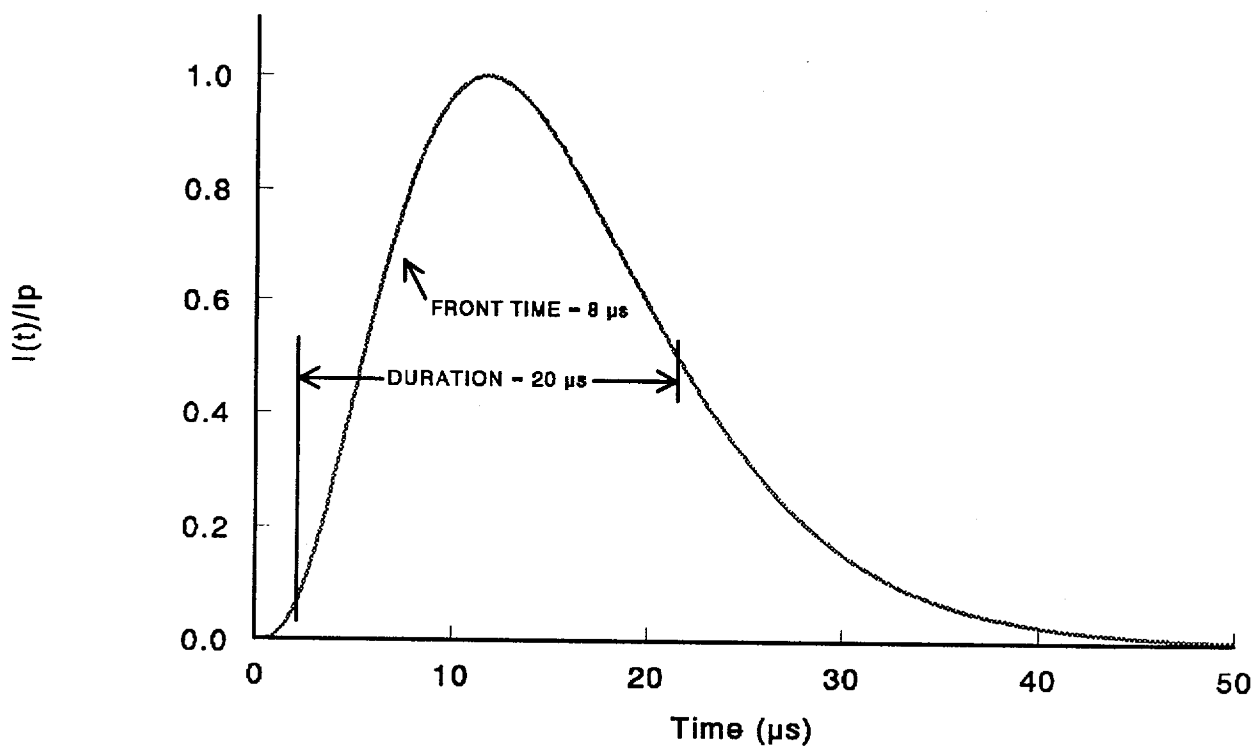

Figure 6.3 Combination Wave, Short-Circuit Current

6.3 Electrically Fast Transients

The EFT waveform consists of repetitive bursts, with each burst containing individual unidirectional pulses, and is intended to represent local load switching on the ac power leads of equipment and subsystems. The individual EFT pulses have a 5-ns rise time and a duration (width at half-maximum) of 50 ns. Plots of the EFT pulse waveform and the pattern of the EFT bursts are shown in Figures 6.4 and 6.5.

The rise time is defined as the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time between the 50% amplitude points on the leading and trailing edges of each individual pulse. Individual pulses occur in bursts of 15 ms duration.

The peak value of the individual EFT pulses should be 3 kV. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the EFT pulses. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

7. DOCUMENTATION

Documentation should be maintained to provide evidence that safety-related I&C equipment meets its specification requirements and is compatible with the projected electromagnetic environment, that the user adheres to acceptable installation practices, and that administrative controls have been established covering the allowable proximity of portable EMI/RFI sources. Data used to demonstrate the compatibility of the equipment with its projected environment should be pertinent to the application and be organized in a readily understandable and traceable manner that permits independent auditing of the conclusion presented.

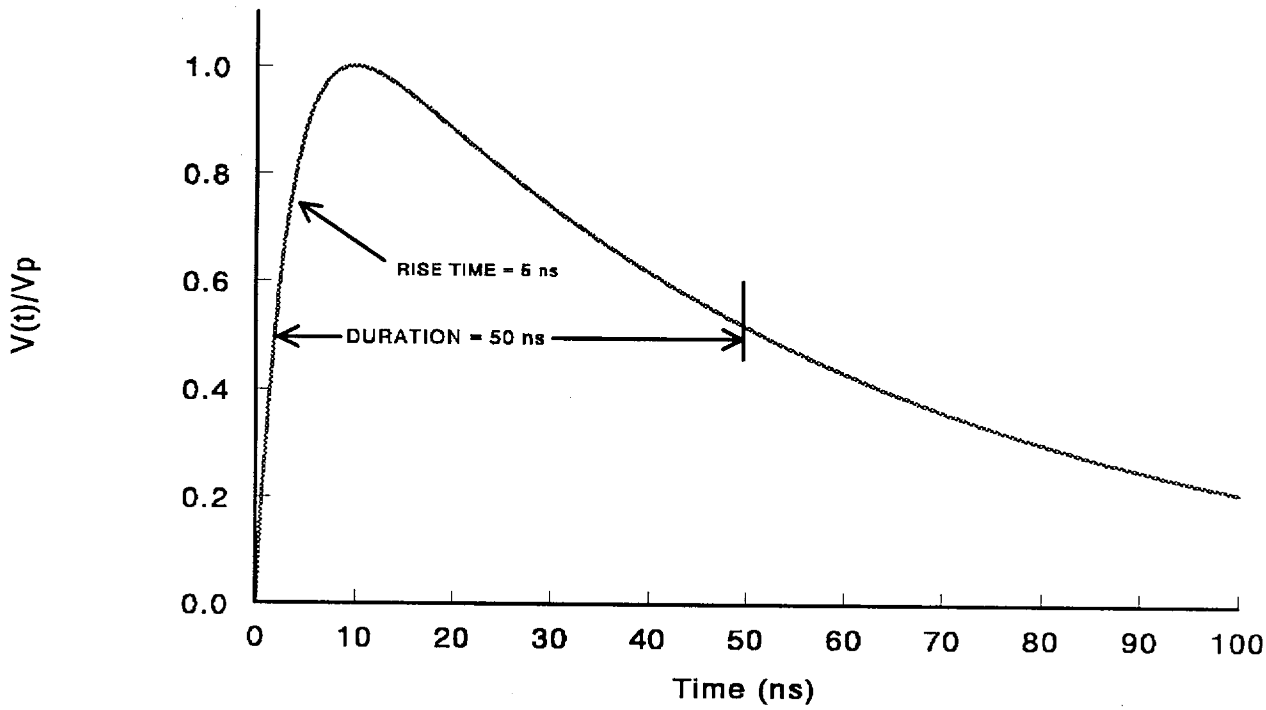

Figure 6.4 Waveform of the EFT Pulse

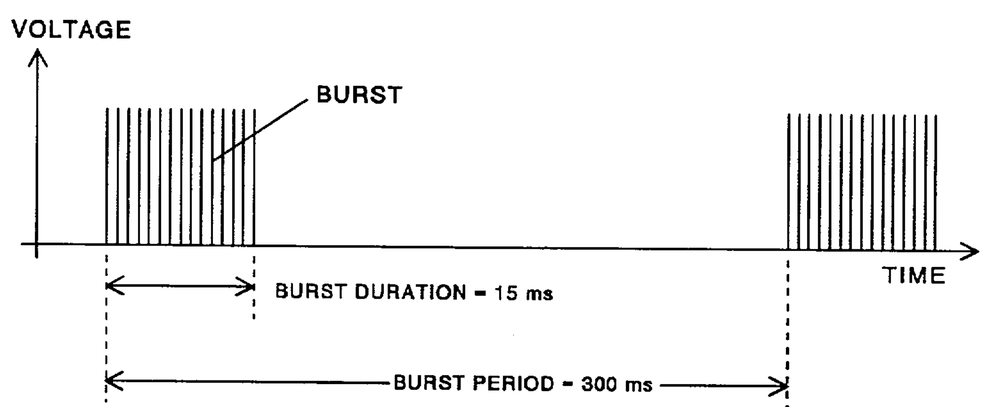

Figure 6.5 Pattern of EFT Bursts

The user should maintain an electromagnetic compatibility report as part of a qualification file (not necessarily at the plant site). Any additional information specified in the standards cited by this regulatory guide should be included in the record as well. The report should contain the information listed below as a minimum.

(1) Identification of the equipment

(2) Specifications on the equipment

(3) Identification of safety functions to be demonstrated by test data

(4) Test plan

(5) Test report, including

    (a) Objective of the test

    (b) Detailed description of test item

    (c) Description of test setup, instrumentation, and calibration data

    (d) Test procedure

    (e) Summary of test data, accuracy, and anomalies

(6) The installation practices employed and administrative controls established to alleviate potential EMI/RFI and power surge exposure

(7) Summary and conclusions

(8) Approval signature and date

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff 's plans for using this regulatory guide.

This draft guide has been released to encourage public participation in its development. Except in those cases in which an applicant or licensee proposes acceptable alternative practices for complying with specified portions of the NRC's regulations, the methods to be described in the active guide reflecting public comments will be used by the NRC staff to address EMI/RFI and power surges in newly installed and upgraded safety-related I&C systems and to demonstrate that they will function according to specifications within the projected electromagnetic environment.

VALUE/IMPACT STATEMENT

Background

This guide is being developed to describe the electromagnetic interference (EMI), radio-frequency interference (RFI), and surge withstand capability (SWC) practices acceptable to the NRC staff with regard to safety-related instrumentation and control (I&C) systems. These practices address design, installation, and testing techniques to minimize electrical noise and reduce the susceptibility of safety-related I&C systems to EMI/RFI and power surges in a nuclear power plant environment.

IEEE Std 1050-1996, "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations," was developed by the Energy Development and Power Generation Committee of the IEEE Power Engineering Society and approved by the IEEE Standards Board. IEEE Std 1050-1996 provides guidance on the design and installation of grounding systems for I&C equipment specific to power generating stations. Its purpose is to achieve both a suitable level of protection for personnel and equipment and suitable electrical noise immunity for signal ground references in power generating stations.

MIL-STD 461, "Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference," and MIL-STD 462, "Measurement of Electromagnetic Interference Characteristics," were developed as measures to ensure the electromagnetic compatibility of equipment. The application of the MIL-STD test criteria and test methods is tailored for the intended function of the equipment and the characteristic environment. These criteria cover conducted and radiated interference (emissions and susceptibility), exposure to electric and magnetic fields, transients, and noise coupling through power and control leads. The MIL-STDs have been used successfully by the U.S. Department of Defense for many years and are commonly referenced in commercial applications.

IEEE Std C62.41-1991, "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits," and IEEE Std C62.45-1992, "IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits," were developed by the Surge Protective Devices Committee of the IEEE Power Engineering Society and approved by the IEEE Standards Board. IEEE Std C62.41-1991 provides guidance for the selection of surge test criteria for evaluating the capability of equipment connected to low-voltage ac power circuits to withstand power surges. The standard also defines a set of surge test waveforms that has manageable dimensions and represents a baseline surge environment. IEEE Std C62.45-1992 provides guidance on the test methods and equipment to be employed when performing the surge tests.

Value

License reviews related to EMI/RFI and power surges in safety-related I&C systems are presently being performed on a case-by-case basis. This guide is being developed to endorse acceptable engineering practices for complying with the NRC's regulations. The value of regulatory guidance is that it (1) offers clear guidance on necessary practices that are a part of an overall EMC program, (2) endorses military and industry standards that have wide, long-standing application, (3) specifies complete suites of EMI/RFI emissions and susceptibility test criteria and methods from the two most prominent military standards and gives operating envelopes that are framed in the proper units and frequency ranges for each specific test method, (4) applies to analog, digital, and hybrid safety-related I&C equipment, and (5) identifies acceptable operating envelopes that are based on similar military environments and confirmed with measurement data from nuclear power plants.

Impact

This guidance is consistent with established practices currently applied throughout the commercial power industry. Therefore, costs associated with the implementation of this guide are expected to be minimal. The guide would apply to both future nuclear power plants and to presently operating nuclear power plants that plan to upgrade safety-related I&C systems.

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